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A LANGUAGE FOR CALCULATING THE ORIENTATION OF A SPACECRAFT

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16. Abstract

The article describes a method for calculating the orientation of a spacecraft. The method is based on the development of a mathematical "language" of elementary concepts describing a spacecraft's orientation parameters. The language is used for constructing the orientation of the Venera Automatic Interplanetary Space Station and is compared with more cumbersome methods.

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A LANGUAGE FOR CALCULATING THE ORIENTATION OF A SPACECRAFT

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One of the important aspects for guidance in space is the /1*
orientation of the spacecraft in the process of executing correction operations, photographing the planets, scientific experiments, et al. It is necessary to make calculations definable by the type of maneuver of the spacecraft and by the characteristics of its orientation system. These calculations can be performed both by ground methods and also independently.

A calculation of the orientation parameters can be rather complex because information processing depending on the particularities of a specific spacecraft and on the type of maneuver is required. For real time calculation conditions the software used must permit the required variations to be readily introduced into the calculation, for example, for a change in the orientation directions, a change of the stars along which orientation is performed, a variation in the quantity and set of defining characteristics, et al.

In this connection there appears the need for constructing a definite mathematical language for describing the orientation parameters and the process for calculating them.

*Numbers in the margin indicate pagination in the foreign text.

The existence of a language assumes, above all, the existence of an "alphabet," i.e., such isolated, elementary concepts from which it is possible to put together any parts into a whole. In the proposed work an attempt is made to compile a catalogue of such concepts relative to the operations which it is necessary to perform for determining the orientation parameters. The operations of the language constitute such a system of concepts.

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The orientation parameters include elementary variables with which one is obliged to operate when compiling programs on a digital computer. Angle, axis, coordinate system, and others are examples of orientation parameters.

The language operations define the actions that can be generated over similar parameters.

The basic operations of the language arise from the following circumstance. When orienting a spacecraft one is practically obliged to align the directions understood in a coordinate system associated with the craft's body with the directions understood in an absolute coordinate system. For example, the directions of the telescopes with the directions to the sun and to a star, the directions of the jet thrust with the direction of the corrective impulse, and others. After such an alignment the coupled coordinate system occupies completely a defined position in space (perhaps with an accuracy to one degree of freedom). Therefore, the concept of alignment of vectors is the basic concept of the proposed language. For this purpose it is necessary, in order to realize it, first, to know how to locate the vectors which must be combined, and, second, to know how to align them. It turns out that it is possible to construct a set of operations solving this problem.

The operations of the described language, according to their degree of complexity, are produced on several levels. Operations over vectors belong to the simplest operations: scalar and vector product, rotation of a vector around a vector at a given angle and others. These simplest operations are used in operations of the next level.

The next level of operations corresponds to actions performed when executing one or another maneuver of the spacecraft. To /3
these operations belong: the determination of the angle of rotation in the plane and on a cone, the operation of alignment, the determination of two [handwritten: and three] angles of a sequential turn. The last level is directly connected with the type of maneuver.

In the proposed language the completeness of the operations at each level is preserved, in the sense that they allow all the operations of the higher level to be executed. The highest level is open, in the sense that one may expand it when there appear new tasks which were not foreseen in the language.

The characteristics of the proposed language for describing the operation of orienting a spacecraft in space is determined by the operations of the highest level. None of the lower levels reflect these characteristics and they can be considered as an expansion of any algorithmic language in the direction of a description of geometrical objects and operations over them in three-dimensional space.

As an example we will consider the operation of constructing a vector on a cone. This operation is basic for fulfilling the concept of locating vectors for their subsequent alignment.

A cone is given with axis of rotation and a given apex angle. In addition, a vector is given, in general not lying on the cone. By means of this operation such a vector is determined which lies on the cone and is located at a given angular distance from the original vector. The problem has two solutions. They are ordered by a definite transform.

In the article an example is presented of the use of a language for calculating the orientation of the Venera Automatic Interplanetary Space Station. For this station there is a description of the principles for constructing systems for orientation and correction in the article of Prof. Raushenbakh [1].

The problem of determining the angles of turn in order to obtain a required orientation from the point of view of the language described reduces to an operation of alignment of the directions to the sun, a star, and of the direction of the corrective impulse (which are understood in an absolute coordinate system) with the directions of the sighting axes of the solar and astro- sensor and of the rocket thrust (which are plotted in the combined coordinate system). The use of the concept of rotations of vectors and coordinate systems for the purpose of aligning directions permits the computation algorithm to be easily described. Only four language operations have to be performed to determine the desired angles of turn. /4

The proposed group of language operations permit us to formalize our thoughts and to register the necessary actions in a concise form. By means of these operations it is possible to solve a large range of problems connected with the orientation of any body in space. The language described has now been written in autocode and run on a BESM-type digital computer [2].

REFERENCES

1. B. V. Raushenbakh. A System of Control for the Venera Interplanetary Automatic Space Station. Kosmicheskiye issledovaniya, Vol. VI, Issue 5, 1968.

2. R. K. Kazakova, A. K. Platonov. A Language for Describing the Rotation of a Spacecraft. Preprint of the Institute of Planetary Mechanics of the Academy of Sciences of the U.S.S.R., No. 59, 1971.

Some Operations of the Language

Level I

Transformation of a Vector (TV)
Transformation of a Coordinate System (TCS)
Transposition (TRAN)
Scalar Product (SCAL)
Vector Product (VECT)

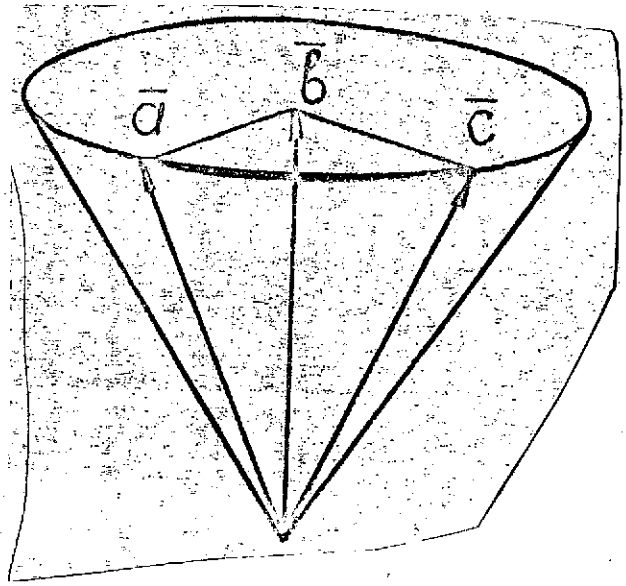
Level II

Construction of a Combined Coordinate System (CCS)
Orthogonalization (ORTH)
Construction of a Vector (COV)
Rotation of a Vector around a Vector (RVV)

Level III

Determination of the Angle of Rotation on a Cone and in the Plane (DARC, DAP)
Alignment (ALIG)
Determination of the Secondary Angle of a Sequential Rotation (SSR)
Determination of the Tertiary Angles of a Sequential Turn (TSR)

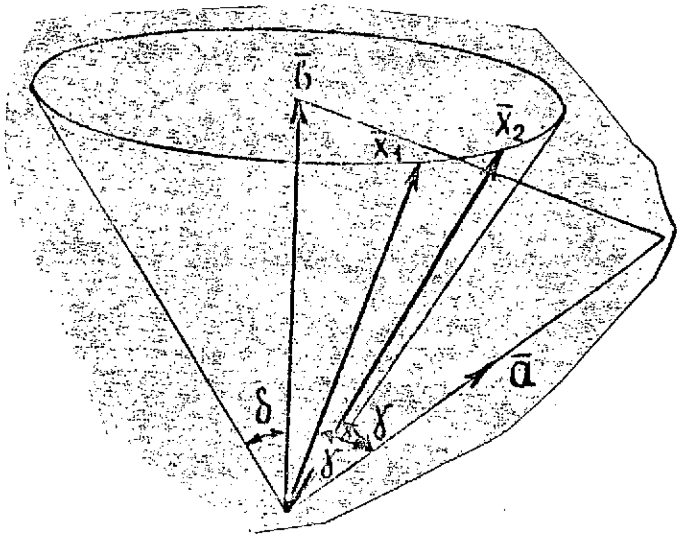
Rotation of a Vector around a Vector (RVV)



treated according to the operation RVV $[\bar{a}, \bar{b}, \varphi; \bar{c}]$

Order of Operations:

1. ORTH $[\bar{b}, \bar{a}; C_1, C_2]$
2. CCS $[\bar{b}, \bar{a}; \Pi_{ij}]$
3. TRAN $[\Pi_{ij}; \Pi'_{ij}]$
4. $\bar{c}_{CCS}$ $[C_2; C_1 \cos\varphi; C_2 \sin\varphi]$
5. $\bar{C} = \Pi'_{ij} \, \bar{C}_{CCS}$



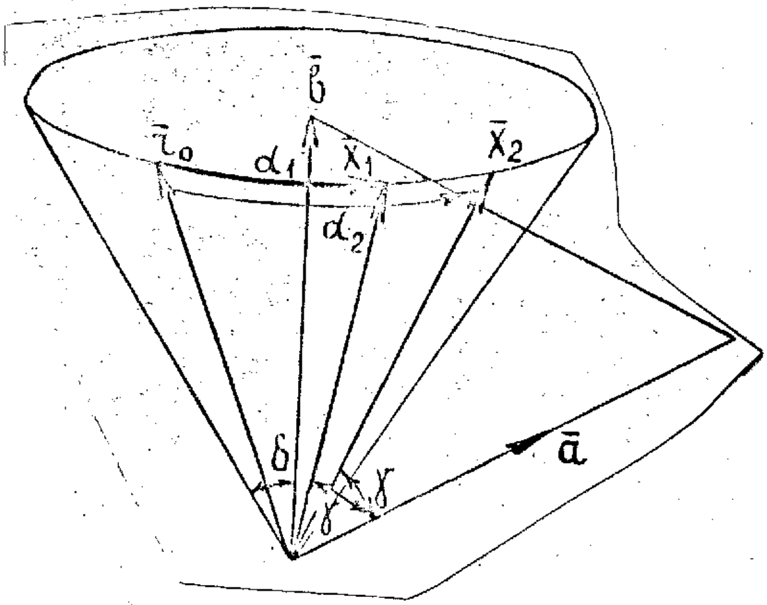
treated according to the operation COV $\left[\bar{b}, \bar{a}, c, f;\ \bar{X}_1^{(1)}, \bar{X}_2^{(2)}\right]$

Order of Actions:

$$\begin{cases} X_1^{(1,2)} = \dfrac{-(A_1A_2+B_1B_2) \pm \sqrt{(A_1A_2+B_1B_2)^2-(A_1^2+B_1^2-D^2)(A_2^2+B_2^2+D^2)}}{A_2^2+B_2^2+D^2} \\ X_2 = \dfrac{A_1+A_2X_1}{D} \\ X_3 = \dfrac{B_1+B_2X_1}{D} \end{cases}$$

Solution 1: $\bar{X}^{(1)}\left(X_1^{(1)}, X_2, X_3\right)$

Solution 2: $\bar{X}^{(2)}\left(X_1^{(2)}, X_2, X_3\right)$



treated according to the operation DARC $\left[\bar{l}_0, \bar{b}, \bar{a}, c; \alpha^{(1)}, x^{(1)}\right]$

Order of Action:

1. SCAL $\left[\bar{l}_0, \bar{l}_0 ; l_0^0\right]$
2. SCAL $\left[\bar{b}, \bar{b} ; \bar{b}^0\right]$
3. SCAL $\left[\bar{a}, \bar{a} ; \bar{a}^0\right]$
4. SCAL $\left[\bar{l}_0^0, \bar{b}^0 ; f = \cos\delta\right]$
5. COV $\left[\bar{b}^0, \bar{l}_0^0, \bar{x}^{(i)} ; \alpha^{(i)}\right]$
6. UMP* $\left[\bar{b}^0, \bar{a}^0, \bar{c}, f ; \bar{x}^{(i)}\right]$

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*Translator's note: Expansion not given.

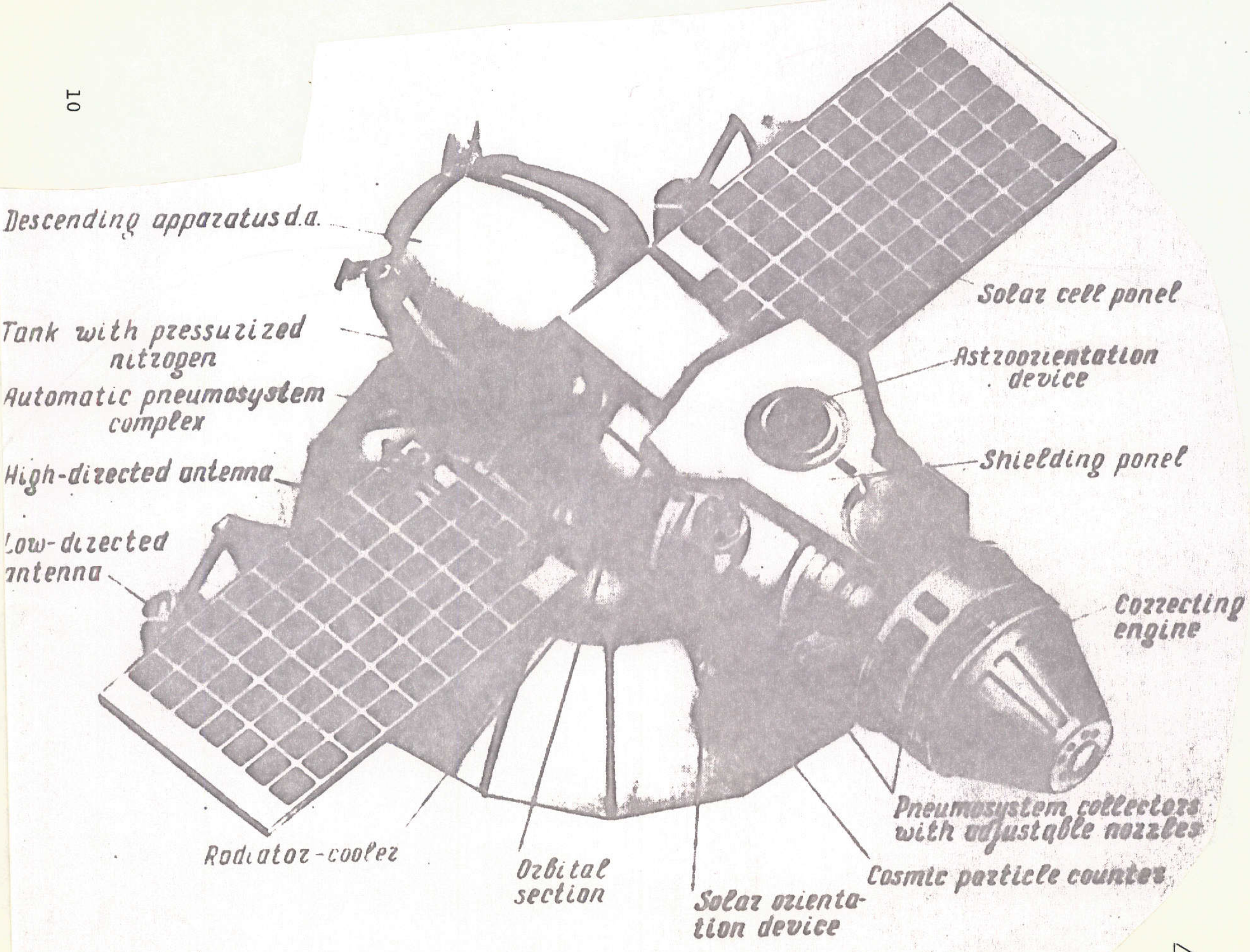

Fig. I. Automatic Interplanetary Space Station Venera 7

1.
$$\bar{V}^0 = \begin{cases} V_x^0 = \dfrac{V_x}{|\bar{V}|} \\ V_y^0 = \dfrac{V_y}{|\bar{V}|} \\ V_z^0 = \dfrac{V_z}{|\bar{V}|} \end{cases} \qquad \bar{S}^0 = \begin{cases} S_x^0 = \dfrac{S_x}{|\bar{S}|} \\ S_y^0 = \dfrac{S_y}{|\bar{S}|} \\ S_z^0 = \dfrac{S_z}{|\bar{S}|} \end{cases} \qquad \bar{K}^0 = \begin{cases} K_x^0 = \dfrac{K_x}{|\bar{K}|} \\ K_y^0 = \dfrac{K_y}{|\bar{K}|} \\ K_z^0 = \dfrac{K_z}{|\bar{K}|} \end{cases}$$

2.
$$\begin{cases} Z_x^{0''} = \dfrac{\sin\Delta\sigma_x \cos\Delta\sigma_y}{\sqrt{1-\sin^2\Delta\sigma_x \sin^2\Delta\sigma_y}} \\ Z_y^{0''} = \dfrac{-\cos\Delta\sigma_x \sin\Delta\sigma_y}{\sqrt{1-\sin^2\Delta\sigma_x \sin^2\Delta\sigma_y}} \\ Z_z^{0''} = \dfrac{\cos\Delta\sigma_x \sin\Delta\sigma_y}{\sqrt{1-\sin^2\Delta\sigma_x \sin^2\Delta\sigma_y}} \end{cases}$$

$$
\left\{
\begin{aligned}
Z_x^{0'} &= \frac{\left[Z_x^{0''} + \frac{\Delta R_x}{|\bar{V}|}\right]_1}{\sqrt{\left[Z_x^{0''} + \frac{\Delta R_x}{|\bar{V}|}\right]_1^2 + \left[Z_y^{0''} + \frac{\Delta R_y}{|\bar{V}|}\right]_2^2 + \left[Z_z^{0''} + \frac{\Delta R_z}{|\bar{V}|}\right]_3^2}} \\
Z_y^{0'} &= \frac{\left[Z_y^{0''} + \frac{\Delta R_y}{|\bar{V}|}\right]_2}{\sqrt{\left[Z_x^{0''} + \frac{\Delta R_x}{|\bar{V}|}\right]^2 + \left[Z_y^{0''} + \frac{\Delta R_y}{|\bar{V}|}\right]_2^2 + \left[Z_z^{0''} + \frac{\Delta R_z}{|\bar{V}|}\right]_3^2}} \\
Z_z^{0'} &= \frac{\left[Z_z^{0''} + \frac{\Delta R_z}{|\bar{V}|}\right]_3}{\sqrt{\left[Z_x^{0''} + \frac{\Delta R_x}{|\bar{V}|}\right]_1^2 + \left[Z_y^{0''} + \frac{\Delta R_y}{|\bar{V}|}\right]_2^2 + \left[Z_z^{0''} + \frac{\Delta R_z}{|\bar{V}|}\right]_3^2}}
\end{aligned}
\right.
$$

3. $$\left.\begin{aligned} \sin\gamma &= |\bar{K}^\circ \times \bar{S}^\circ| \\ \cos\gamma &= \bar{K}^\circ \cdot \bar{S}^\circ \end{aligned}\right\} \angle\gamma$$

4. $$A = \frac{[\bar{K}^\circ \times \bar{S}^\circ]}{\sin\gamma} \cdot \bar{V}^\circ \; ; \qquad B = (\bar{S}^\circ \cdot \bar{V}^\circ)$$

$$C = \frac{(\bar{K}^\circ \cdot \bar{V}^\circ) - (\bar{S}^\circ \cdot \bar{V}^\circ)\cos\gamma}{\sin\gamma}$$

$$|Z_p^{0'}| = \pm\sqrt{1 - (Z_x^{0'})^2 - B^2}$$

5. $$\left.\begin{aligned} \sin\psi &= \frac{Z_p^{0'} A + Z_x^{0'} C}{A^2 + C^2} \\ \cos\psi &= \frac{Z_p^{0'} C - Z_x^{0'} A}{A^2 + C^2} \end{aligned}\right\} \angle\psi$$

6.

$$\left.\begin{aligned}\sin(\tilde{\theta}-\Delta\sigma_x) &= \frac{(\bar{V}^{\circ}\cdot\bar{S}^{\circ})}{\sqrt{1-(Z_0^{0'})^2}} \\ \cos(\tilde{\theta}-\Delta\sigma_x) &= \frac{A\sin\psi + C\cos\psi}{\sqrt{1-(Z_0^{0'})^2}}\end{aligned}\right\}\quad \begin{aligned}\tilde{\theta} &= (\tilde{\theta}-\Delta\sigma_x)+\Delta\sigma_x \\ \theta &= \tilde{\theta}-\frac{\pi}{2} \\ \theta &= \begin{cases}\theta, & \text{if } \theta>0 \\ \theta+2\pi, & \text{if } \theta<0\end{cases}\end{aligned}$$

Computation of the Orientation of the Venera Automatic Station by Means of the Language Operations /11

1. SCAL $\left[\bar{V}, \bar{S};\ \cos C\right]$

2. DARC $\left[(\bar{Z}'+\Delta\bar{\sigma})^{0}, (\bar{X}'+\Delta\bar{X}), (\bar{Z}'+\Delta\bar{R}), \cos C; \bar{X}^{(i)}, \Theta^{(i)}\right]$

3. COMB $\left[\bar{V}^{0}, \bar{S}^{0}, (\bar{Z}'+\Delta\bar{R}), (\bar{Z}'+\Delta\bar{\sigma});\ a_{ij}\right]$

4. Choice of Solution:

from the angles $\theta^{(i)}$ that solution is chosen for which

$\bar{K}^{\circ} \cdot \bar{X} \wedge 0 \quad (i = 1, 2)$

5. SSR $\left[(\bar{Z}'+\Delta\bar{\sigma}), (\bar{X}'+\Delta\bar{X}), a_{ij}, \bar{X}^{(i)}, \bar{K}^{0};\ \psi^{(i)}, \gamma^{(i)}, A^{\psi(i)}, A^{\gamma(i)}\right]$

6. Choice of Solution:

from the angles $\psi^{(i)}$ there is selected $0° \leq \psi \leq 180°$.

" " " $\gamma^{(i)}$ " " " $0° \leq \gamma \leq 180°$.